Modelling the Effectiveness Cascade for Malaria Case Management in Rwanda

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Declaration

I, **Martin HABIMANA**, hereby declare that this thesis entitled "Modelling the Effectiveness Cascade for Malaria Case Management in Rwanda" is my original work and has not been submitted elsewhere for examination, award of a degree, or publication. Where other people's work or my own work has been used, it has been properly acknowledged and referenced in accordance with AIMS Rwanda's requirements.

Student's Signature:

Date: December 19, 2024

I, **Dr. Monica Golumbeanu**, confirm that I have reviewed this thesis entitled "Modelling the Effectiveness Cascade for Malaria Case Management in Rwanda," and it has been submitted with my approval.

Supervisor's Signature:

Date: December 19, 2024

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Abstract

Malaria continues to be a pressing health issue in Sub-Saharan Africa, particularly in Rwanda, where it affects countless lives and strains the Rwanda healthcare system. This study models the effectiveness of uncomplicated malaria case management using a decision tree framework that accounts for factors such as: health-seeking behavior, provider compliance, patient adherence, and drug quality. Based on data from the Demographic and Health Surveys (DHS) and Malaria Indicator Surveys (MIS) from 2000 to 2020. Our study revealed a notable increase in effective malaria treatment coverage, from just 7% in 2000 to 46% in 2020, meaning that by 2020, nearly half of the malaria cases were managed effectively. Access to care improved significantly, rising from 11% to 62% nationally, with Kigali showing the highest rates at 71%, reflecting better healthcare infrastructure in urban areas. However, rural regions in the North and West are still lagging, though slowly catching up. Compliance with first-line antimalarial therapy (ACT) for children under five peaked at 98.5% in 2017 but slightly declined to 92.9% in 2020, which could indicate potential challenges in maintaining treatment consistency. Additionally, the quality of antimalarial drugs persists a concern, with 17% of artemether-lumefantrine and 33% of sulfadoxine-pyrimethamine sourced from informal providers being substandard, threatening treatment success. To further reduce malaria cases, we recommend Enhancing patient education to improve treatment adherence, Strengthening diagnostic capabilities to ensure accurate treatment, implementing robust systems for monitoring drug resistance, improving supply chain management to maintain drug quality and early treatment, and Providing continuous training for healthcare workers especially Community Health Works on evolving treatment guidelines.

Acronyms

ACTs Artemisinin-based Combination Therapies

AL Artemether-Lumefantrine

CHWs Community Health Workers

DHS Demographic and Health Survey

FY Fiscal Year

HBM Home-Based Management

iCCM Integrated Community Case Management

IPT Intermittent Preventive Treatment

IRS Indoor Residual Spraying

ITNs Insecticide-Treated Nets

IV Intravenous

LLINs Long-Lasting Insecticidal Nets

MIS Malaria Indicator Survey

MSP Malaria Strategic Plan

PMI President's Malaria Initiative

RDTs Rapid Diagnostic Tests

SLDPQ Single Low-Dose Primaquine

WHO World Health Organization

MOPDD Malaria and Other Parasitic Diseases Division

MCM Malaria Case Management

AIMS African Institute of Mathematical Science

AIMS RIC AIMS Research and Innovation Center

HBM Home-based Management for Malaria

Contents

1. Introduction

1.1 Background

Malaria continues to be a pressing health issue in Sub-Saharan Africa [4], particularly in Rwanda, where it affects countless lives and strains the healthcare system. Picture a young child in a rural village, feeling feverish and weak due to malaria, with parents worried about accessing proper and effective treatment on time. Despite substantial efforts and progress in reducing malaria prevalence in Rwanda, malaria is still a burden, particularly in rural areas where access to healthcare services remains limited [8]. The effectiveness of malaria case management is a critical component of the overall strategy to control and eventually eradicate malaria. This study focuses on modelling the effectiveness cascade for malaria case management in Rwanda, which involves understanding the various stages from the onset of symptoms to being cured from malaria.

The past decade has witnessed a notable reduction in malaria-related mortality and morbidity across sub-Saharan contries and other regions, thanks to the extensive scale-up of preventive and control measures [10]. National malaria control programs, supported by the global community, have been pivotal in averting an approximately 274 million incidences of malaria and 1.1 million associated mortalities, showcasing the significant impact of concerted efforts in combating the malaria disease [7]. Sustaining these achievements, however, hinges not only on continued resource allocation but also on the performance of health systems in managing malaria cases effectively.

Malaria case management plays a crucial role in individual and public health. Effective treatment not only cures the infection and prevents severe malaria but also reduces the infectious reservoir within the community, curbing the spread of disease. Early and accurate diagnosis helps ensure efficient use of antimalarial medications, while completing the full course of treatment eradicates parasites and lowers the risk of drug-resistant strains emerging. Understanding and improving case management is therefore essential for refining control and elimination strategies, ultimately contributing to the global effort against malaria [13].

The current global guidelines for malaria case management, provided by the World Health Organization (WHO), emphasize prompt and accurate diagnosis using microscopy or RDTs before treatment, recommending ACTs for uncomplicated *P. falciparum* malaria and chloroquine or ACTs for *P. vivax, P. malariae,* and *P. ovale* infections, with specific guidelines for severe cases, pregnant women, infants, and young children [11]. The guidelines also advocate for intermittent preventive treatment (IPT) for high-risk groups, vector control through ITNs and IRS [11]. Despite the availability of effective treatments, many malaria patients still lack access to appropriate care or experience delays in seeking treatment. Compliance with treatment guidelines by healthcare providers may be inconsistent, leading to instances where patients receive incorrect medications or dosages. Even when correct treatment is administered, challenges such as patient non-adherence and the use of counterfeit or substandard drugs contribute to treatment failures and facilitate the development of drug resistance [7].

The national treatment guidelines for malaria in Rwanda outline specific protocols for managing both uncomplicated and severe cases of the disease. For uncomplicated malaria, the first-line treatment recommended is AL. In cases of complicated malaria, the preferred treat-

ment is intravenous (IV) Artesunate, with IV Quinine serving as an alternative. Special considerations are made for pregnant women. For prevention, the guidelines strongly recommend sulfadoxine-pyrimethamine (SP) as an intermittent preventive treatment. For treating malaria during pregnancy, oral quinine plus clindamycin is advised during the first trimester for uncomplicated cases, while AL is recommended during the second and third trimesters. In severe cases during the first trimester, IV Quinine is strongly recommended.

Parenteral artesunate is the preferred treatment for severe malaria in all patients, except for pregnant women in their first trimester, who are still advised to receive intravenous quinine, contrary to WHO guidelines [6]. Rwanda's national treatment guidelines have been updated to include rectal artesunate as an initial (pre-referral) treatment for severe malaria, recommended solely for children aged six months to six years. This approach is limited to district, provincial, and referral hospitals for managing severe malaria cases [6].

The integration of CHWs into the healthcare delivery system has been a cornerstone in extending healthcare services, including malaria case management, to the rural and hard-to-reach populations. This integrated approach not only improves accessibility to healthcare services but also enhances the quality of care provided at the community level [16]. Rwanda has a robust CHW program, which includes community case management through integrated Community Case Management (iCCM) for diseases such as malaria, diarrhea, and pneumonia in children under five. Additionally, it features HBM, which focuses on malaria treatment for individuals aged five years and older. The nationwide network of 58,000 CHWs includes two CHWs per village, trained to perform malaria testing with RDTs and provide treatment at the community level. In the fiscal year 2020, 58 percent of all malaria diagnoses and treatments in Rwanda were conducted at the community level [6]. The MOPDD uses RapidSMS (transitioning to RapidPro) a rapid, secure short message service (SMS) system introduced in late 2018 for coordination of severe malaria case referral from CHWs to health facilities and for commodities stock management [6].

Currently, around 57% of all malaria cases are diagnosed and treated by CHWs, with a goal to increase this to 80%. This target aims to be achieved through a consistent supply of RDTs and ACTs [6].

The effectiveness of malaria case management is influenced by several health system factors. Key supply-side determinants include access to diagnostic tools, availability of trained staff, and the consistent supply of antimalarial drugs at healthcare facilities [7]. On the demand side, factors such as patient awareness, perception of illness, affordability of treatment, and adherence to prescribed regimens significantly influence malaria management. Evaluating the limits of health systems in delivering ACTs effectively and understanding the impact of informal care providers are critical for a comprehensive assessment of malaria case management.

The present study focuses on building a model of the case management care cascade in Rwanda. Several components, such as access to treatment, provider compliance, adherence, and cure rate, are modeled and informed with routine and survey data. These individual components are integrated into a decision tree model and used to estimate effective coverage of malaria case management in Rwanda. Specifically, we aim to determine the proportion of malaria cases effectively managed by the healthcare system and identify key inefficiencies in service delivery that impact patient outcomes.

1.2 Problem Statement

Malaria is a major health problem in Rwanda, and effective treatment is essential to reducing its impact. However, several challenges often undermine the effectiveness of malaria case management. Many people have trouble accessing health facilities, delaying or preventing them from getting the right treatment, and even when they do reach the healthcare system, healthcare providers sometimes do not follow national treatment guidelines, resulting in sub-optimal treatment being prescribed. Even when patients receive the proper treatment, poor adherence to the full course of medication and the use of substandard medicines contribute to treatment failures and the continued emergence of drug resistance. While these barriers are recognized, there is currently a gap in knowledge about how these factors collectively influence the overall effectiveness of malaria case management in Rwanda. Understanding and addressing these barriers in the malaria case management cascade is essential for improving the overall effectiveness of malaria treatment in Rwanda. However, a model that measures the treatment effectiveness specifically within Rwanda has not yet been developed. This research seeks to fill this gap by creating a model that illustrates the effectiveness cascade of malaria case management in Rwanda. The model evaluates components such as: access to care, provider compliance, patient adherence, and drug quality, to estimate the overall effectiveness of malaria case management.

1.3 Objectives

1.3.1 General Objective.

The study aims to estimate the effective coverage of malaria case management in Rwanda using data from Demographic and Health Survey (DHS) and Malaria Indicator Survey (MIS) conducted during the period [2000-2020].

1.3.2 Specific Objectives.

- To construct and validate a decision tree model for estimating the effective coverage of malaria case management, incorporating factors such as care-seeking behavior, health provider type, treatment compliance, and drug efficacy.
- To utilize data from Demographic and Health Surveys (DHS) and Malaria Indicator Surveys (MIS) conducted between 2000-2020 to inform and populate the components of the care cascade model.
- To estimate the effective coverage of malaria case management at both national and regional (admin 1) levels in Rwanda using the developed model and available data.
- To compare the estimated effective coverage of Malaria Case Management from our model with the effective coverage reported from the Malaria Atlas Project at both the national and provincial levels.

1.4 Thesis Organization

This thesis is structured into five main chapters:

1. **Introduction:** This chapter provides the background and context of the study, outlines the objectives, presents the problem statement, and describes the organization of the thesis.
2. **Literature Review and Current Prescriptives:** This chapter examines global and regional perspectives on malaria control, discusses progress and challenges in malaria control and case management, focuses on malaria case management in Rwanda, and provides an overview of recent relevant studies.
3. **Methodology:** This chapter details the estimation methodology employed in the study and describes the data analysis techniques used.
4. **Results:** This chapter presents the findings of the study, including key performance indicators for malaria services, overall effective coverage of malaria case management, the impact of performance indicators on the level of effective coverage, and a discussion of these results.
5. **Conclusion:** The final chapter summarizes the main findings of the study and discusses their implications for malaria control efforts in Rwanda.

2. Literature Review

2.1 Progress and Challenges in Malaria Control

Rwanda has made significant strides in reducing the burden of malaria over the past decade, highlighted by the drop in malaria's ranking as a leading cause of death among children under five from the top position in 2005 to fourth in 2012. Despite this progress, recent years have seen a troubling rise in malaria cases, rising from 112 per 1,000 in 2013-2014 to 308 per 1,000 in 2015-2016, with all 30 districts in Rwanda at risk. This increase has been attributed to several factors, including non-universal coverage of effective interventions such as Long-Lasting Insecticidal Nets (LLINs) and Indoor Residual Spraying (IRS), resistance to pyrethroid insecticides, climate change, environmental modifications, and population movement [17].

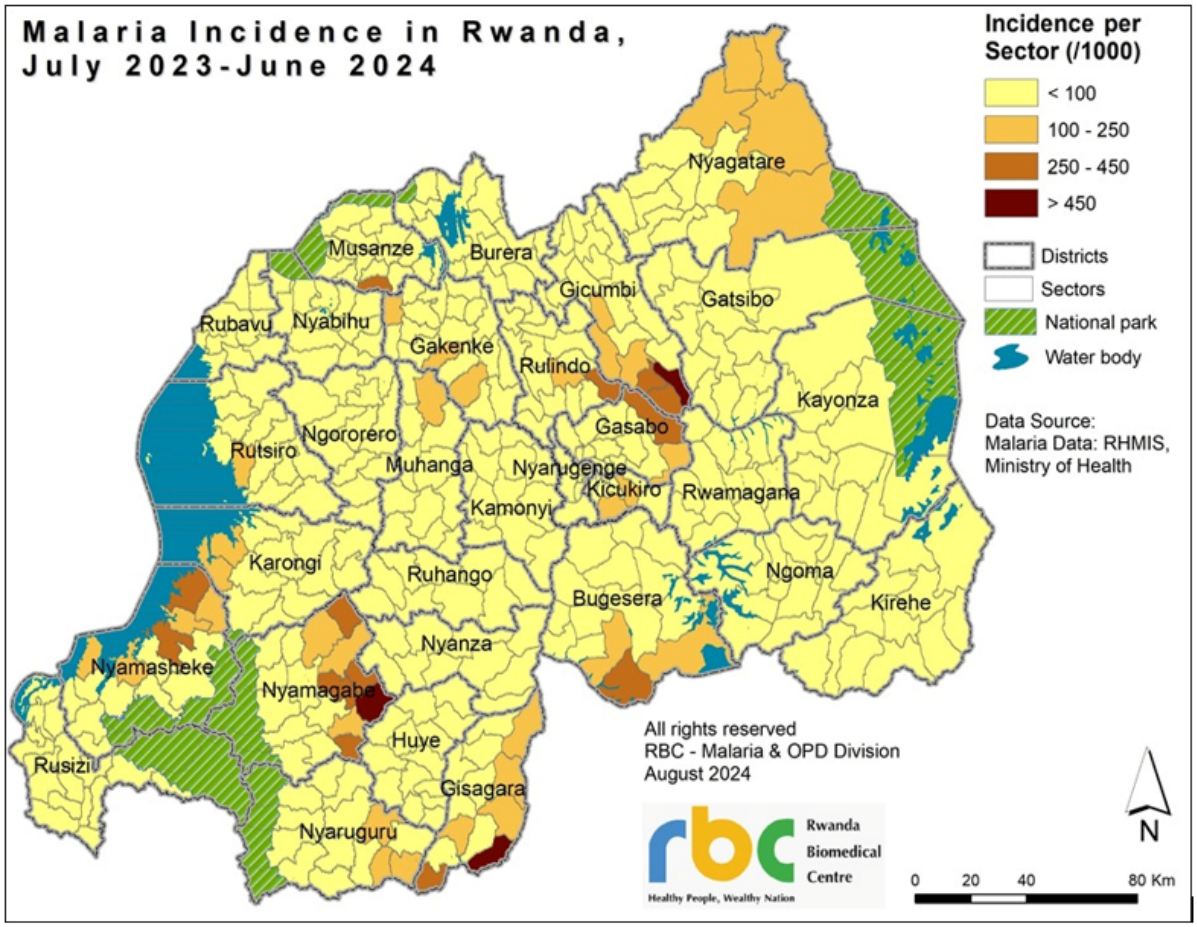

Figure 2.1: Malaria Incidence in Sectors (**Source:** Malaria Annual Report FY 2023-2024)

In response to the rising malaria cases, the Government of Rwanda, in partnership with other stakeholders, implemented several interventions, including the development of a Malaria Contingency Plan, and has been actively implemented since the mid-2010s. Key strategies included expanding the Home-Based Management of fever, which was previously limited to children, to also include adults at the community level, the distribution of over six million mosquito nets across the country, the expansion of IRS in high-burden districts, and the

reinforcement of communication strategies focused on environmental hygiene, appropriate use of treated bed nets, and seeking early treatment.

Most districts in Rwanda have a malaria incidence rate below 100, with only three sectors marked in dark red exhibiting incidence rates exceeding 450 (Figure 2.1). A focused investigation was conducted in Gisagara and Nyagatare districts, where malaria incidence remains high. This investigation aimed to identify key risk factors contributing to the persistence of malaria in these areas.

In Gisagara, factors such as the proximity to large rice fields, which provide breeding grounds for mosquitoes, and insufficient coverage of indoor residual spraying (IRS) were found to be significant contributors. In Nyagatare, the high malaria burden is primarily linked to its geographic location near the Akagera wetlands, where stagnant water creates ideal mosquito breeding habitats. Additionally, both districts suffer from challenges in consistent use of insecticide-treated bed nets and delays in seeking prompt treatment for malaria, exacerbating the spread of the disease.

2.2 Malaria Case Management in Rwanda

Malaria case management in Rwanda faces several obstacles and gaps that hinder effective prevention and treatment efforts. Major challenges include limited access to healthcare services, particularly in rural regions, and a lack of adequately trained healthcare professionals, which leads to delays in diagnosis and treatment. The situation is further complicated by inadequate diagnostic tools, frequent shortages of essential antimalarial drugs, and poor compliance with treatment protocols. Additionally, inconsistent use of insecticide-treated nets (ITNs), growing insecticide resistance, and weak surveillance systems weaken malaria prevention and control measures.

Malaria case management is directed by the Malaria Strategic Plan (MSP) 2020–2024, which seeks to ensure 100% timely testing and treatment of all suspected malaria cases, following the National Malaria Treatment Guidelines. This approach ensures that all suspected cases of uncomplicated malaria undergo universal, high-quality parasitological testing, followed by rapid treatment of confirmed cases using artemisinin-based combination therapy (ACT) [5]. The strategy also includes the pre-referral and definitive treatment of severe febrile illnesses and severe malaria. The U.S. President's Malaria Initiative (PMI) supports this strategy by providing funding for national policies, program activities, and the procurement of essential supplies, such as ACTs [5]. At the community level, the Rwanda National Malaria Treatment Guidelines recommend using dual antigen rapid diagnostic tests (RDTs) for malaria, with the Government of Rwanda and the Global Fund procuring the necessary RDTs, while PMI focuses on providing ACTs [6].

Rwanda's community health worker (CHW) program is a critical component of its malaria case management strategy. With approximately 58,000 CHWs deployed across the country, including in rural areas, the program ensures that basic care, integrated community case management (iCCM), and home-based management (HBM) of malaria are accessible to the population.PMI assists in training, supervising, and mentoring these CHWs, with approximately 57% of malaria diagnoses and treatments happening at the community level. Despite the advancements, challenges persist, including the continued use of a paper-based system

for data recording. PMI and other partners are working to address this by promoting the digitalization of community health services.

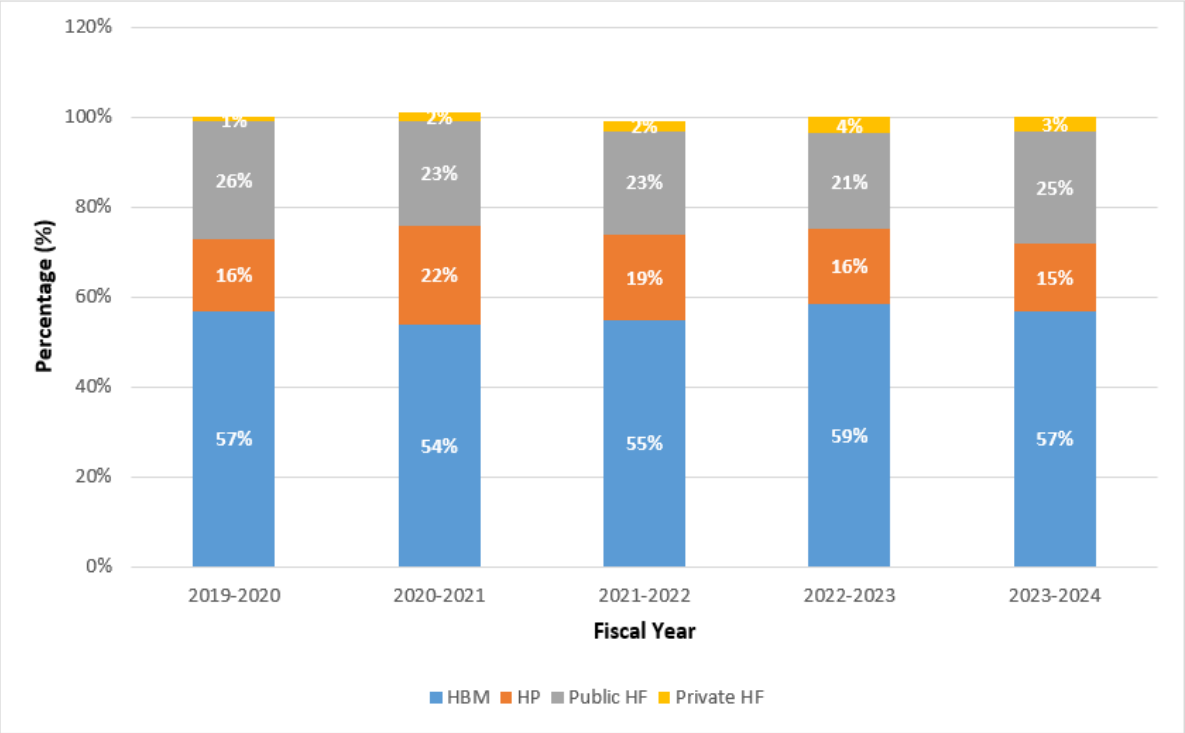

Figure 2.2: Proportion of Malaria Cases Treated by Level of Service Delivery (**Source:** Malaria Annual Report FY 2023-2024.)

The proportion of malaria cases treated in the community remains above 57% since the scale up of the home-based management of simple malaria to adults (Malaria Annual Report FY 2023-2024) (Figure 2.2).

In response to the rising prevalence of the k13 561H mutation, which is linked to delayed parasite clearance, efforts are being made to address this growing concern [19]. Rwanda's Malaria and Other Parasitic Diseases Division (MOPDD) is exploring innovative strategies. Measures include piloting the use of single low-dose primaquine (SLDPQ) in districts where the mutation has been documented and implementing multiple first-line therapies in various geographic regions to preserve the effectiveness of the current ACT partner drug, lumefantrine [5]. While artemether-lumefantrine (AL) remains the first-line treatment in most districts, dihydroartemisinin-piperaquine (DP) is being considered as an alternative in select districts to safeguard against drug resistance.

2.3 An overview of Recent Studies

Galactionova et al. (2015) looked at how effective is malaria treated in Sub-Saharan Africa, focusing on factors like how often people seek treatment, whether they follow treatment guidelines, patient adherence, and the quality of drugs. They used data from DHS/MIS and other sources, to estimate that effective coverage of malaria treatment varies widely, from 8% to 72% across 43 high-burden countries, revealing big gaps and inefficiencies. Despite the availability of effective treatments, poor management remains a problem, adding to the high burden of malaria. The study also highlights the lack of good data, especially on how well health providers and patients adhere to treatment and the quality of medications, which makes it hard to accurately assess the situation in individual countries [7]. In Rwanda, the median health care seeking rate is reported at 59%. This study shows Rwanda as one of the few countries achieving nearly perfect compliance with first-line antimalarial therapy, alongside Botswana, Malawi, São Tomé and Príncipe, Somalia, and Zambia. Approximately 90% of fevers in Rwanda are treated with the first-line antimalarial.

The World Malaria Report 2022 provides valuable insights into malaria treatment-seeking behaviors and the use of artemisinin-based combination therapies (ACTs) in Rwanda. It revealed that 62.9% of individuals experiencing fever sought treatment, with 60.9% receiving a diagnostic test. However, only 12.2% of those who sought care were treated with ACTs. Among those who underwent a diagnostic test, such as a finger or heel prick, ACT usage increased slightly to 18.9%. Importantly, 92.3% of patients who received any form of antimalarial treatment in Rwanda were administered ACTs [13].

The Malaria Atlas Project (MAP) provides the trend in national effective coverage of malaria case management from 2000 to 2021 (Figure 2.3). The Malaria Atlas Project (MAP) is a global initiative dedicated to collecting, analyzing, and distributing spatial data on malaria risk and related metrics. It employs advanced geospatial modeling techniques to create high-resolution maps of malaria prevalence and associated factors. MAP collects data from various sources, including surveys, surveillance systems, and research studies, and is committed to making its findings freely accessible to researchers, policymakers, and the public. The project's interdisciplinary approach combines expertise from epidemiology, statistics, geography, and public health to support evidence based decision making in malaria control strategies. MAP's outputs are crucial for monitoring changes in malaria transmission over time and evaluating the effectiveness of interventions. Its work has significantly influenced our understanding of malaria's global distribution and has been instrumental in shaping malaria control policies worldwide [9].

It shows a general upward trend in effective coverage of malaria case management in Rwanda over the past two decades, starting from about 0.27 in 2000 and reaching approximately 0.37 by 2021. There was initial volatility in the early 2000s, with a decrease to around 0.23 in 2003, followed by a steady increase until 2013. The coverage peaked around 2016-2017 at nearly 0.38, after which a slight decline is observed (Figure 2.3).

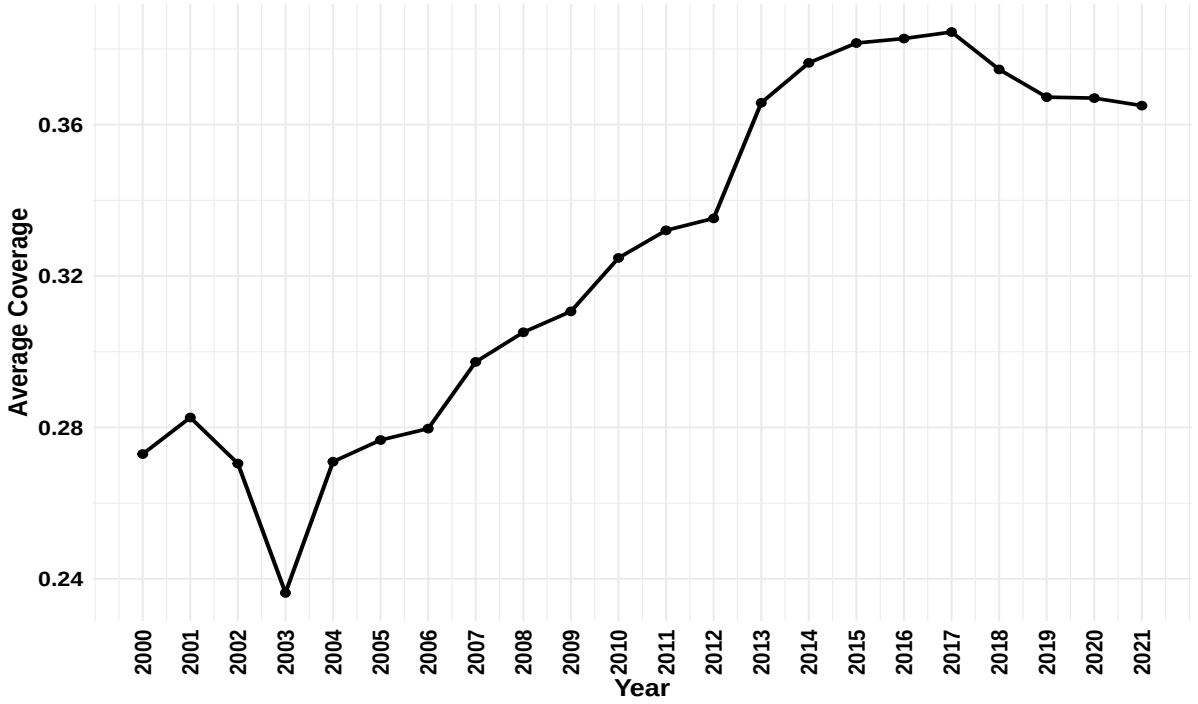

Figure 2.3: Effective Coverage of Malaria Case Management 2000-2021 (**Source:** Malaria Atlas Project.)

According to the Malaria Atlas Project, the effective coverage of malaria case management across All provinces in Rwanda from 2000 to 2021, show a general upward trend in effective coverage over the 21 years period, indicating improved malaria case management across Rwanda.

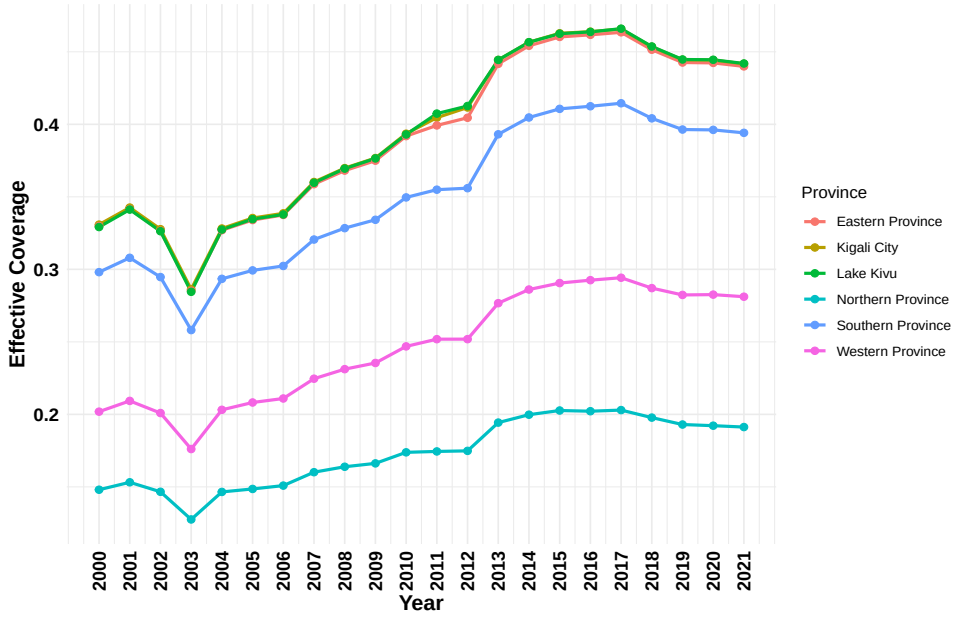

Figure 2.4: Effective Coverage of Malaria Case Management by Province (**Source:** Malaria Atlas Project.)

Kigali City and Eastern Province consistently show high coverage, both reaching approximately 47% coverage by 2017. In contrast, Northern Province consistently has the lowest coverage, starting at around 15% in 2000 and reaching about 19% by 2021. Southern Province demonstrates the most significant improvement, rising from around 30% to 39%. Interestingly, the gap between the highest and lowest coverage provinces narrows over time, decreasing from about 18 percentage points in 2000 to 30 percentage points in 2021. Most provinces reach peak coverage around 2016-2017, followed by a slight decline. For instance, Kigali City peaks at about 51% in 2016 before slightly decreasing to 49% by 2021. A common decrease in coverage is observed across all provinces around 2002-2003, with Lake Kivu, for example, dropping from about 34% in 2001 to 28% in 2003. Western Province, starting as the second-lowest at about 20% in 2000, shows steady growth to reach approximately 28% by 2021. These trends provide insights into the evolving healthcare landscape across Rwanda's provinces over two decades (Figure 2.4).

3. Methodology

3.1 Estimation Framework

To estimate the effectiveness of uncomplicated malaria case management in Rwanda, we use a decision tree model (Figure 3.1) that captures the key factors influencing treatment success. This model starts with a malaria fever episode and expands to outline treatment-seeking behavior, the type of healthcare provider consulted, adherence to recommended antimalarial therapy, and treatment regimen compliance, along with cure rates considering drug quality, resistance, and clinical effectiveness. This methodology aims to estimate the likelihood of achieving both clinical and parasitological cure for a malaria fever episode, thus providing a measure of effective coverage (E).

Algebraically, effective coverage (E) is defined as a function of health-seeking behavior (A), scaled down by a weighted average cure rate of antimalarial treatments (T_{pd}) across various drugs (d) and providers (p) (Equation 3.1.1):

$$\begin{aligned} E &= A\left(\sum_p P_p\left[\sum_d D_{pd}H_{pd}T_{pd}\right]\right). \\ &= AP_fD_{fs}H_{fs}T_{fs} + AP_fD_{fa}H_{fa}T_{fa} + AP_iD_{is}H_{is}T_{is} + AP_iD_{ia}H_{ia}T_{ia}. \end{aligned} \tag{3.1.1}$$

Where: $\sum_p P_p = 1, \quad \sum_d D_{pd} = 1$

The cure rate T_{pd} accounts for treatment failure due to inadequate quality of medications Q_{pd}, resistance R_d, and clinical efficacy of the antimalarial therapy C_d:

$$T_{pd} = (1 - Q_{pd})(1 - R_d)(1 - C_d). \tag{3.1.2}$$

Where:

- Q_{pd} represents the proportion of antimalarial treatments d provided by provider p that are of substandard quality.
- R_d is the proportion of episodes caused by parasites resistance to drug d.
- C_d is the parasitological failure rate of sensitive parasites for drug d.
- $0 \leq Q_{pd}$, R_d, and $C_d \leq 1$.

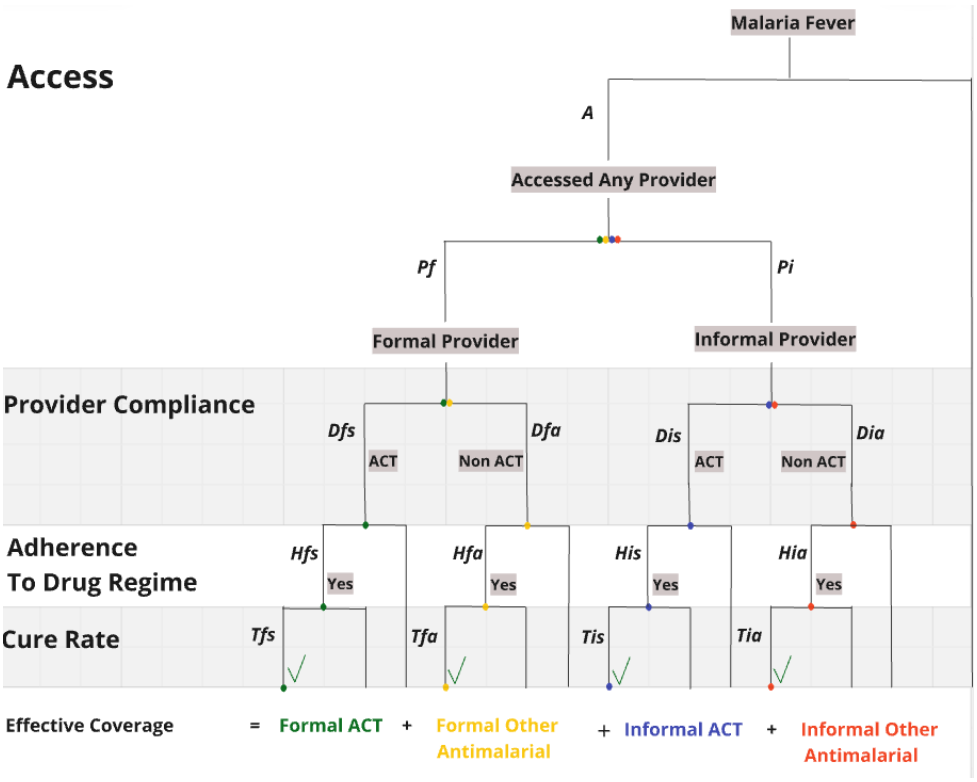

Figure 3.1: Decision Tree Model of Case Management Cascade of Uncomplicated Malaria.

Parameter	Description
A	Proportion of malaria fevers for which care is sought.
P_p	Proportion of care-seeking malaria fever episodes that access health care provider *p*.
D_{pd}	Proportion of malaria fever episodes treated by provider *p* with anti-malarial therapy *d*.
H_{pd}	Proportion of fever cases treated with drug *d* by provider *p* that adhere to the regimen.
T_{pd}	Cure rate of antimalarial therapy *d* obtained from provider *p*.
P_f	Proportion of formal health care provider.
P_i	Proportion of informal health care provider.
D_{fs}	Proportion of malaria fever cases treated by a formal provider with artemisinin-based combination therapy (ACT).
D_{fa}	Proportion of malaria fever episodes treated by formal provider with other antimalarial therapy.
D_{is}	Proportion of malaria fever episodes treated by informal provider with antimalarial therapy of ACT.
D_{ia}	Proportion of malaria fever episodes treated by informal provider with other with other antimalarial therapy.

H_{fs}	Proportion of fever cases treated with ACT by formal provider that adhere to the prescribed drug regimen.
H_{is}	Proportion of fever cases treated with an ACT drug by informal provider that adhere to the prescribed drug regimen.
H_{fa}	Proportion of fever cases treated with antimalarial drug by formal provider that adhere to the prescribed drug regimen.
H_{ia}	Proportion of fever cases treated with other antimalarial drug by informal provider that adhere to the prescribed drug regimen.
T_{fs}	Cure rate of ACT therapy obtained from formal health care provider.
T_{fa}	Cure rate of other antimalarial therapy obtained from formal health care provider.
T_{is}	Cure rate of ACT therapy obtained from informal health care provider.
T_{ia}	Cure rate of other antimalarial therapy obtained from informal health care provider.

Table 3.1: List of Parameters in Model

3.2 Data Collection and Preprocessing

The definitions, data sources, and key assumptions for each parameter specified in the model are outlined in (Table 3.2) and described below it. Indicators related to malaria fever services, types of care providers, and provider compliance are gathered and measured using data from the DHS and MIS.

DHS and MIS data were directly downloaded from the DHS website and loaded in R using haven library for Stata (.dta) file formats. Specifically, I utilized the dplyr and tidyverse libraries for data manipulation and analysis. Our focus was on recoding DHS/MIS survey variables related to fever, health-seeking behavior, and drug treatments to derive effective malaria coverage for Rwanda, administrative region (admin1), and survey. The Rcode for this methodological framework, originally created by Katya Galactionova and converted from Stata to R by Rémi Turquier.

Model Input	Notation	Definitions	Data Source	Assumptions
Access to Any Healthcare Provider	A	Proportion of <5 fevers for which care is sought	DHS/MIS	It was assumed that if no accessed health care provider, the effective coverage is zero.
Access to a Formal Healthcare Provider	$P_p\|p = f$	Proportion of access for which care is sought from a formal care provider	DHS/MIS	Formal providers were categorized as those recognized as legal by the Rwandan government.
Access to an Informal Healthcare Provider	$P_p\|p = i$	Proportion of access for which care is sought from an informal care provider	DHS/MIS	we assume that informal providers are illegal healthcare providers as defined by the government.
Compliance	$D_{pd}\|d = a$	Proportion of treated <5 malaria fevers that receive first-line antimalarial therapy (ACT)	DHS/MIS	All malaria-related fevers for which treatment is sought are treated with an antimalarial drugs.
Noncompliance	$D_p\|d = s$	Proportion of treated <5 malaria fevers that receive antimalarial therapy other than first-line	DHS/MIS	All malaria-related fevers for which treatment is sought are treated with an antimalarial drugs.
Adherence	H_d	Proportion of treated <5 malaria fevers that adhere to the prescribed drug regimen (d=a: first line ACT regimen; d=s: other)	Katya'a Paper [7]	100% failure rate for partially adherent treatments
Cure Rate	T_{pd}	Efficacy of antimalarial drugs taking into account clinical and parasitological failure rate C_d, resistance R_d, and incidence of counterfeit medications Q_{pd}.	Katya's Paper [7]	The Cure rate is assumed to be the same in all years
Effective Coverage	E	Proportion of <5 malaria fevers cured	Derived	Effective Coverage is zero if no accessed health care provider

Table 3.2: Overview of Definitions, Data Sources, and Essential Assumptions for Malaria Service Performance Indicators

3.2.1 Calculation of Access to Treatment (parameters A, P_f, P_i).

Access estimates, the proportion of malaria fevers seeking care (A) in (Equation 3.1.1) were derived from the Demographic and Health Survey (DHS) data. To calculate access, we identified whether the child was alive which is indicated by ('b5') a variable in DHS dataset and whether child had fever in last two weeks before survey ('h22') and sought treatment from any of type of healthcare providers ('h32'). If treatment was sought within 24 hours, this was considered timely access and coded as '1', whereas cases treated later or not at all were coded as '0'. The data columns used in this analysis included indicators of had fever in last two weeks ('h22'). To determine the proportion of children with fever who accessed treatment, the analysis specifically considered the proportion of cases coded as "1," indicating that child was alive, had fever and sought treatment.

The classification of care providers into formal and informal groups was based on data from the Demographic and Health Survey (DHS) and Malaria Indicator Survey (MIS). Formal providers,

recognized and authorized by the Government of Rwanda, include government referral hospitals, provincial and district hospitals, health centers, health posts, community health workers, and other public sector facilities. Private entities such as polyclinics, pharmacies, clinics, dispensaries, and other private medical entities are also considered formal providers. In contrast, informal providers, which do not have formal recognition, include kiosks or shops, traditional healers, churches, friends or relatives, and other non-regulated sources of care.

To estimate P_f and P_i, we considered variables indicating the type of healthcare provider accessed. These ranged from government facilities ('h32a' to 'h32g') and private medical entities ('h32j' to 'h32n') for formal providers to informal providers ('h32s' to 'h32v'). These variables differ across various years of DHS datasets, reflecting changes in healthcare access patterns over time. By categorizing each child who sought care based on the type of provider accessed, we computed P_f as the proportion of children with fever who accessed formal providers and P_i as the proportion who accessed informal providers. It was assumed that if no care providers were accessed, the effective coverage was zero.

3.2.2 Calculation of Provider Compliance (parameters D_{fs}, D_{fa}, D_{is}, D_{ia}).

Compliance with first-line antimalarial therapy was estimated using data from DHS and MIS surveys conducted in Rwanda between 2000 and 2020. The surveys provided detailed information on antimalarial treatments received by individuals with fever, including artemisinin-based combination therapy (ACT), particularly artemether-lumefantrine (AL), as well as other antimalarials such as SP/Fansidar, chloroquine, amodiaquine, quinine, and artesunate. The analysis pipeline recoded these drug variables, categorizing them as first-line (typically ACTs) or other antimalarials. Compliance was calculated separately for formal and informal healthcare sectors.

We estimated the following parameters D_{fs}, D_{fa}, D_{is} and D_{ia} in equation (3.1.1) from the DHS datasets of year 2000 to 2020, we examined specific rows that indicate the type of antimalarial therapy used. The rows labeled h32a to h32y in DHS dataset identify the type of provider where treatment was sought, such as government hospitals (h32a), health centers (h32c), community health workers (h32f), private clinics (h32l), etc. We focused on formal providers (e.g., hospitals, health centers, etc) for D_{fs} and D_{fa} calculations, and on informal providers (e.g., shops, traditional healers) for D_{is} and D_{ia}. For the type of antimalarial therapy, we looked at rows ('h37a') to ('h37y') in the DHS dataset, which specify whether ACT or other antimalarials were used, such as ('h37e') for ACT and ('h37d') for quinine but these lows varies across different DHS datasets. By using these rows, we calculated the proportions of malaria fever episodes treated by each provider type, categorizing the treatments into those provided by formal or informal providers and those using ACT or other antimalarials (non ACT). We assumed that patients who completed at least three days of ACT drug treatment achieved therapeutic drug levels. while those with partial adherence likely remained parasitemic.

3.2.3 Calculation of Adherence (parameters H_{fs}, H_{fa}, H_{is}, H_{ia}).

Adherence values were incorporated as fixed assumptions in the calculation of effective coverage for malarial treatments. These values were not estimated from the DHS survey data itself, but rather derived from existing literature. Galactionova et al. 2015 [7] is a source for informing these assumptions. For first-line antimalarials (ACTs), adherence was assumed to be 80% in the formal sector and 64% (80% of adherence of first-line antimalarials (ACTs)) in the informal sector [7]. Adherence for first-line ACT and other antimalarials was assumed to be the same in formal providers and informal providers.

3.2.4 Calculation of the Cure Rate (parameters T_{fs}, T_{fa},T_{is},T_{ia}).

The cure rate (T_{pd}) was estimated by considering several critical factors affecting the effectiveness of antimalarial drugs. This estimate incorporates the treatment failure rates associated with inadequate medication quality (Q_{pd}), resistance (R_d), and the overall clinical efficacy of the therapy (C_d). Specifically, the efficacy of antimalarial drugs is influenced by clinical and parasitological failure rates (C_d), resistance (R_d), and the incidence of sub-optimal formulations (Q_{pd}). These variables were extracted from the research literature. The cure rates for antimalarial treatments have been derived from clinical studies conducted between 2012 and 2018, as reported in the World Health Organization's "Report on Antimalarial Drug Efficacy, Resistance and Response: 10 Years of Surveillance (2010–2019)." The results indicate that the cure rate for Artemether-lumefantrine over a 28-day follow-up period is approximately 96.8%, calculated by subtracting the treatment failure rate of 3.2% from 100% [12].

3.3 Linear Model and Analysis

3.3.1 Methodology.

The purpose of the analysis was to investigate the relationship between effective coverage of malaria case management (dependent variable *eff_cov*) and three independent variables: access to health-care (*access*), compliance with malaria treatment guidelines (*compl_f*), and the role of the formal health-care sector in healthcare provision (*formal*).

We used a simple linear regression model to quantify the relationship between these variables for each year between 2000 and 2020. The regression equation expressed as:

$$\text{eff\_cov} = \beta_0 + \beta_1(\text{access}) + \beta_2(\text{compl\_f}) + \beta_3(\text{formal}) + \epsilon$$

Where:

- *eff_cov* represents effective coverage.
- β_0 is the intercept.
- β_1, β_2, β_3 are the coefficients representing the effect of *access*, *compliance*, and *formal* respectively on *eff_cov*.
- ϵ is the error term.

3.3.2 R Packages Used.

Several R packages were used to preprocess the data, conduct the analysis, and visualize the results:

- **readxl**: To read and load CSV files into R for each year's dataset.
- **tidyverse**: A collection of packages like *dplyr*, *ggplot2*, *tidyr*, and *readr* for data manipulation, visualization, and analysis.

  - *dplyr*: For data manipulation and cleaning (e.g., selecting and renaming columns).
  - *ggplot2*: For creating scatterplots to visualize the relationships between the variables.
  - *tidyr*: To reshape the data for visualization, using functions like *pivot_longer()*.
- **scales**: For customizing axes and formatting scales in the plots.
- **gridExtra**: To arrange multiple plots in a grid layout.

3.3.3 Assumptions of Linear Regression.

In applying a linear regression model, several assumptions were made about the data:

- **Linearity**: We assumed that the relationship between the independent variables (*access*, *compliance*, *formal sector*) and the dependent variable (*effective coverage*) is linear. This assumption was tested by plotting the data and fitting a linear trend line using *geom_smooth (method = "lm")*.
- **Independence**: It was assumed that the observations in the dataset are independent of each other.
- **Homoscedasticity**: The variance of the residuals (errors) was assumed to be constant across all levels of the independent variables.

3.4 Sample Sizes across different Surveys Datasets

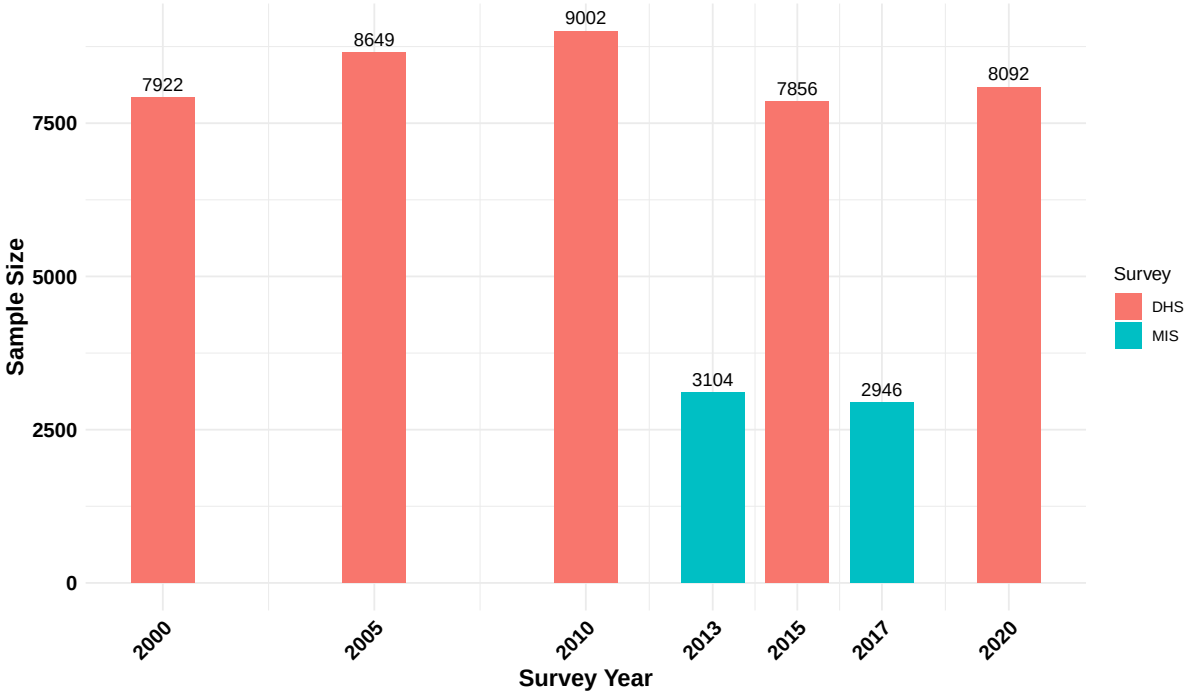

Figure 3.2: Sample sizes for various surveys conducted in Rwanda from 2000 to 2020

4. Results

4.1 Key Performance Indicators for Malaria Case Management Services

Data Source. The analysis presented in this study utilized datasets from the Demographic and Health Survey (DHS) and Malaria Indicator Survey (MIS) conducted in Rwanda between 2000 and 2020. We successfully extracted data and estimated effective coverage at both national and provincial level. The specific DHS years included were 2000, 2005, 2010, 2015, and 2020, and 2008, 2013, and 2017 for MIS. These datasets provided information on healthcare-seeking behaviors, treatment access, and antimalarial drug used.

Access to malaria case management. Access to healthcare across Rwanda has shown significant improvements over the past two decades. In 2000, access was notably low across the country, with a national average of 11% and significant regional disparities. By 2020, access had increased to 62% nationwide, reflecting substantial progress in healthcare delivery. Kigali consistently led with the highest levels of access, reaching 71% by 2020, while regions like the South and East saw remarkable improvements, narrowing the gap between urban and rural areas. Despite this progress, some regions such as the West and North still lagged slightly behind, though their access levels also showed notable gains, reaching over 60% (Figure 4.2).

Provider compliance and Patient Adherence. The analysis of compliance to first-line antimalarial therapy (ACT) for treated malaria fevers in children under 5 in Rwanda demonstrates a fluctuating but generally improving trend over the past two decades. In 2000, the national compliance rate was 50.8%, indicating that just over half of treated malaria cases in children under 5 received the recommended ACT. This rate saw a significant decline to 29.2% in 2005, possibly reflecting challenges in the initial rollout or adoption of ACT as the first-line treatment. However, subsequent years showed marked improvement. By 2010, the compliance rate had dramatically increased to over 90%, suggesting a successful widespread implementation of ACT protocols. The following years saw some fluctuation: 69.3% in 2013 and 48.4% in 2015, which might indicate periodic challenges in drug supply or changes in treatment guidelines. Notably, there was a substantial improvement to 98.5% in 2017, approaching near-universal compliance with ACT for treated childhood malaria cases. The most recent data from 2020 shows a slight decrease but still maintains a high compliance rate of 92.9%. When treated with an ACT we find that patients generally adhered with the drug regimen over 80% of patients completed the recommended 3-day course (Figure 4.2).

Drug quality and resistance. The review of existing research suggests that approximately 17% of artemether-lumefantrine (ALU) medications obtained from informal sources like pharmacies and shops are substandard or low quality. This percentage varies widely, from 0% to 62%. For sulfadoxine-pyrimethamine (SP) medications, the situation appears worse, with an average of 33% being counterfeit, ranging from 0% to 66%. While artemisinin-based combination therapies (ACTs) continue to be effective in Sub-Saharan Africa, other antimalarial drugs face significant resistance issues. The failure rate for non-ACT antimalarials is estimated to be between 20% and 69% across the region. For the purpose of calculating effective coverage, we used the middle value, assuming that SP treatment is ineffective in about 40% of cases [7].

4.2 National Effective Coverage of Malaria Case Management

Using our model informed with the DHS and MIS data, the estimated effective case management shows a consistent improvement over the two-decade period. Over the 20-year period, Rwanda has made substantial progress in improving the effective coverage of malaria case management, increasing from about 7% to 46%. It indicates that by 2020, nearly half of all malaria fever cases in Rwanda were effectively treated.

In 2000, the effective coverage was very low, at approximately 7%. However, there was a sharp increase to about 24% by 2005, indicating significant progress in the first five years. The upward trend continued steadily, reaching around 35% in 2010 and peaking at about 43% in 2013. There was a slight decline to 38% in 2015, but the coverage rebounded and

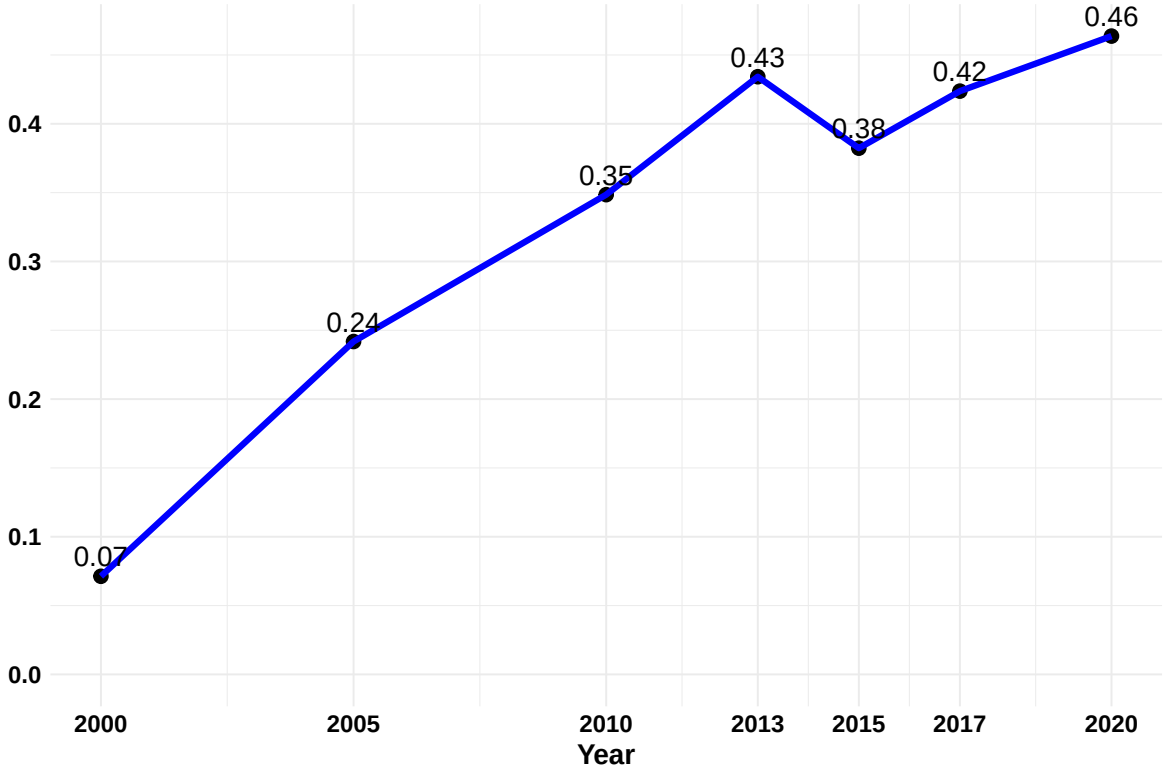

Figure 4.1: Malaria case management effective coverage in Rwanda, 2000-2020

continued to improve thereafter, reaching approximately 42% in 2017 and culminating at the highest point of about 46% in 2020. This overall positive trend suggests that Rwanda has been continously making an effort in improving the effective coverage of malaria case management over the past 20 years, with the most recent data (DHS 2020) showing nearly half of malaria cases receiving effective management (Figure 4.1).

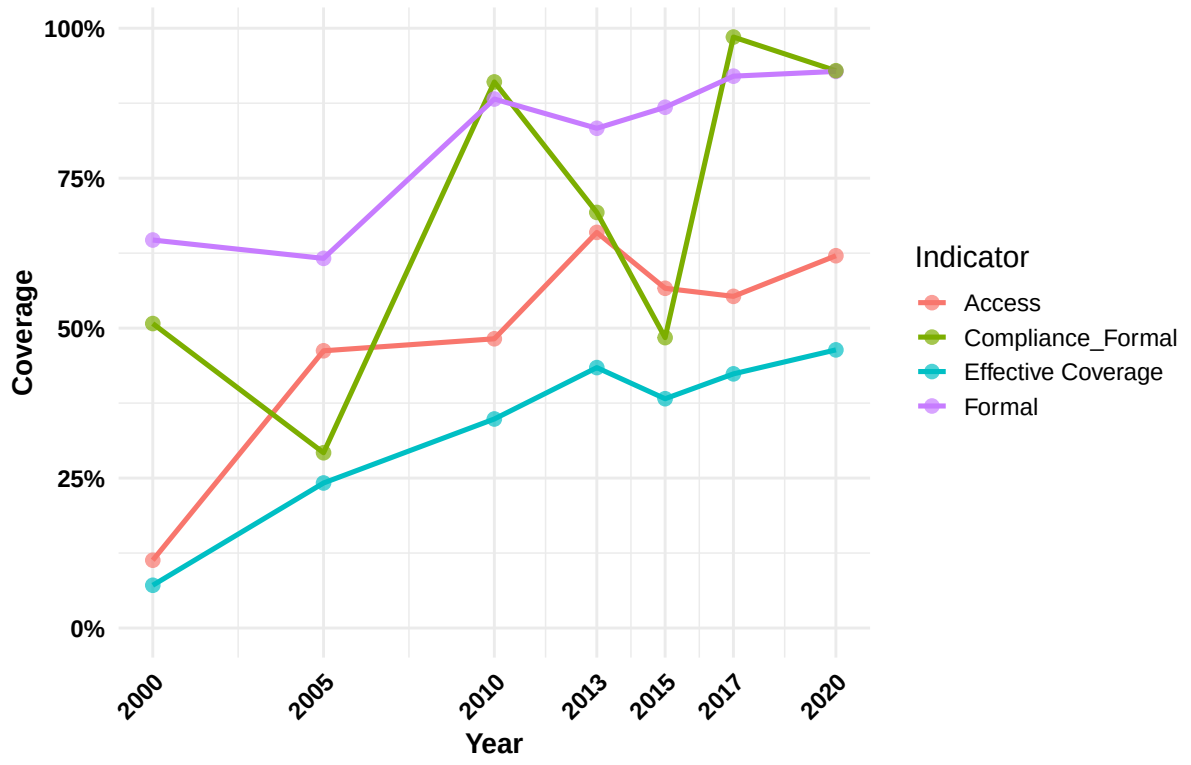

Figure 4.2: Coverage for Malaria Case Management indicators in Rwanda, 2000-2020

Access to malaria care services increased markedly from about 10% to over 60%, while compliance with treatment protocols (compl-f) saw the most dramatic rise, peaking at nearly 100% before slightly declining to 95% by 2020. Formal health care seeking also grew substantially, starting at 62% and reaching over 90% by 2020. It appears to be influenced by the trends in the other indicators, particularly access and compliance to the treatment policy. As access to care and compliance to treatment protocols improved, the effective coverage increased correspondingly. The relationship suggests that expanding access and improving treatment compliance are crucial (Figure 4.2).

In the analysis, we applied the model at the provincial level, covering the different regions of Rwanda: Kigali City, East, North, South, and West. All provinces show a general upward trend in effective coverage of malaria case management over the two decades, indicating overall improvement in malaria case management throughout the country. However, there are notable variations among the regions.

4.3 Effective Coverage of Malaria Case Management at provincial Level

Kigali consistently maintained the highest effective coverage throughout most of the period, starting at about 11% in 2000 and reaching approximately 53% by 2020 (Figure 4.3).

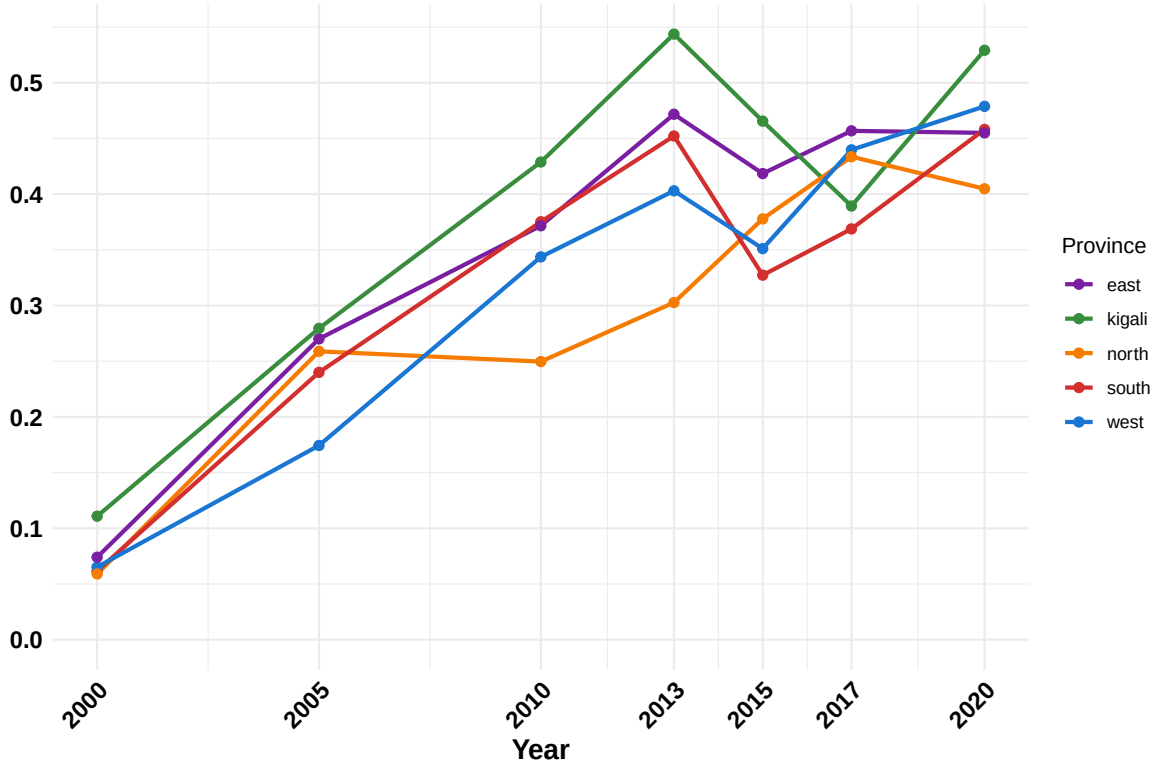

Figure 4.3: Effective Coverage Over the 20 Years by Province Level, 2000-2020

It shows a sharp increase in 2013, peaking at nearly 54%, followed by a decline to 39% in 2017, and then rising again to 53% in 2020. The West region shows steady improvement, starting around 7% in 2000 and reaching about 48% by 2020. It closely follows Kigali's trend, often having the second-highest coverage. The Southern region displays almost a similar trajectory to the West, beginning at about 6% in 2000 and climbing to roughly 46% by 2020. It experiences a notable decrease in 2015 before recovering. The Northern region shows the most stable growth pattern, starting lowest at about 6% in 2000 but achieving consistent improvement to reach around 41% by 2020. The Western region initially lags behind but shows rapid improvement after 2010. Starting at about 7% in 2000, it reaches approximately 48% by 2020, surpassing all regions except Kigali in the 2020 year. All regions experience a significant jump in effective coverage between 2010 and 2013. The period from 2013 to 2015 shows some volatility across all regions, with most experiencing a decline followed by recovery. By 2020, the effective coverage values for all regions converge more closely than at any previous point, ranging from about 41% to 54%, showing a reduction in regional disparities over time (Figure 4.3).

4.4 Coverage for Malaria Case Management indicators by Province

4.4.1 Access to the Treatment at Provincial Level.

There's a general upward trend in access coverage for all regions over the 20-year period. Initially in 2000, all regions had very low access to treatment coverage, between 10% and 20%. There was a sharp increase in access coverage for all regions between 2000 and 2005 (Figure 4.4).

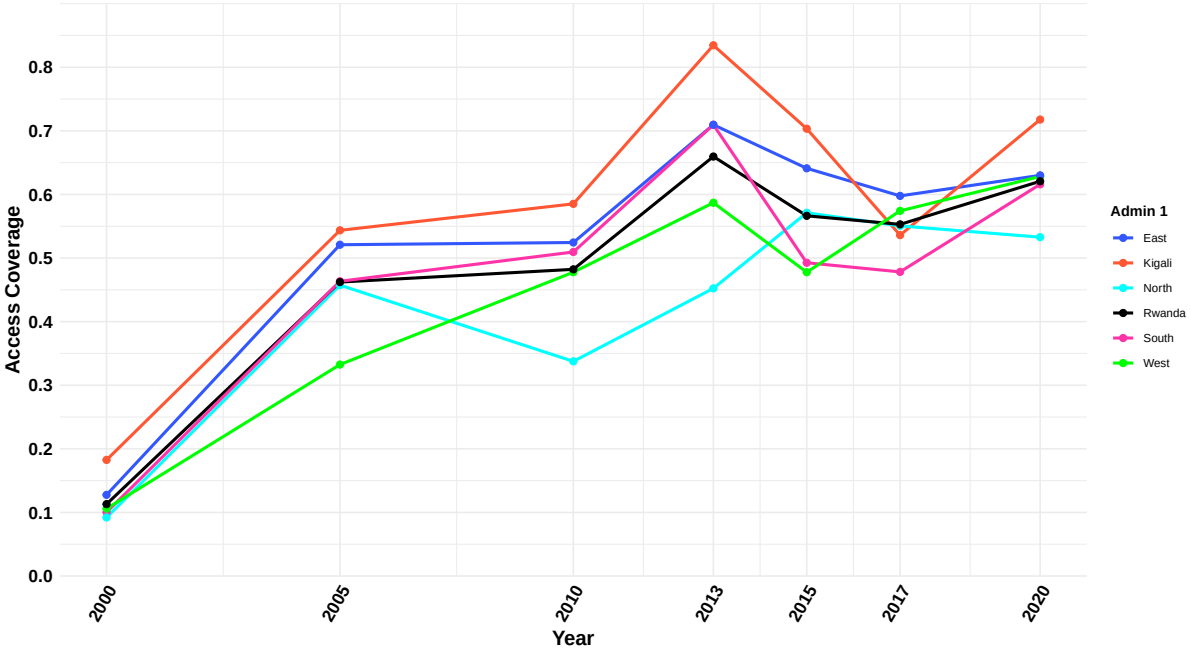

Figure 4.4: Trends in Access to Malaria Treatment Across Rwanda's Provinces

By 2020, the access to the treatment coverage for most regions converges between 60% and 70%, with Kigali still leading at around 72%. The Western province had the lowest access to treatment for many years but shows steady improvement, catching up with other regions by 2020.

4.4.2 Compliance With Firstline Antimalarial Drug at Provincial Level.

The compliance with firstline antimalarial (ACT) rates went up and down a lot, Around 2005, very few people were taking firstline antimalarial drug correctly (15-40%). There is a dramatic improvement, with compliance peaking at 80-100% across all regions after decreasing in 2005. The East consistently stayed behind other provinces.A sharp increase occurred around year 2017 and 2020, with rates back up to near 100% and 85-95% respectively. Kigali city, generally maintained higher compliance rates, especially in later years (Figure 4.5).

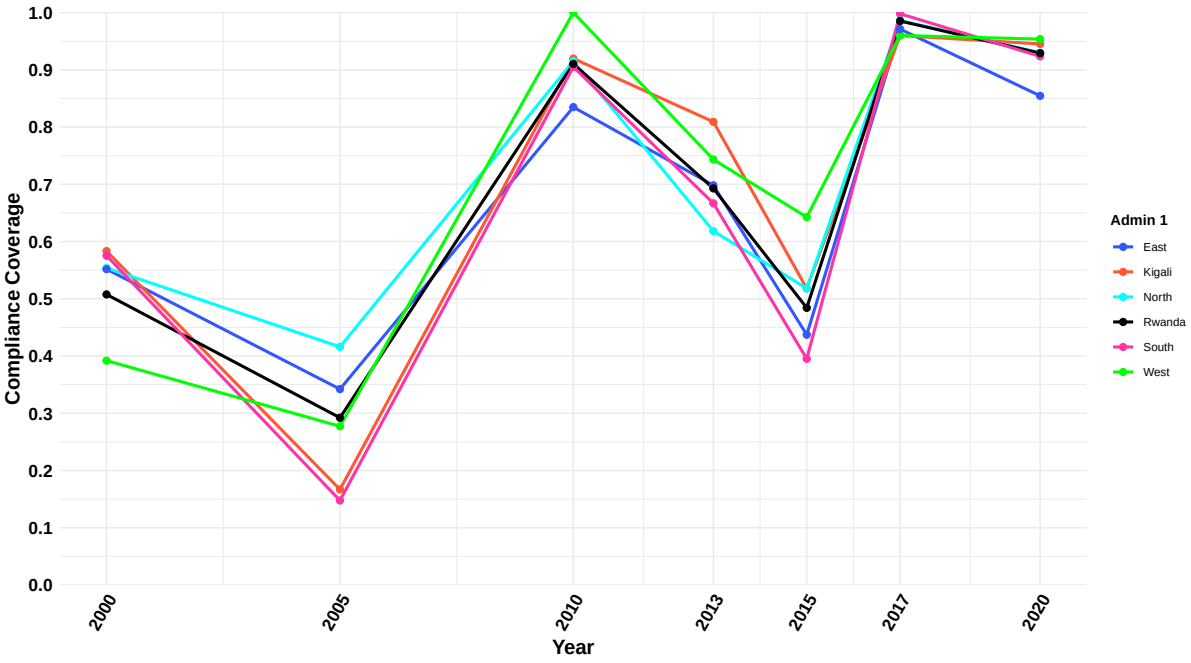

Figure 4.5: Compliance with First-line Antimalarial Drugs Trends Across Provinces

4.4.3 Formal Healthcare Provider at provincial Level.

All provinces show an increase in proportion of patient accessing formal healthcare providers, especially after 2005. Most Provinces have achieved a high level of proportion of patient accessed formal healthcare provider, ranging from 90% to 95%, by 2020.

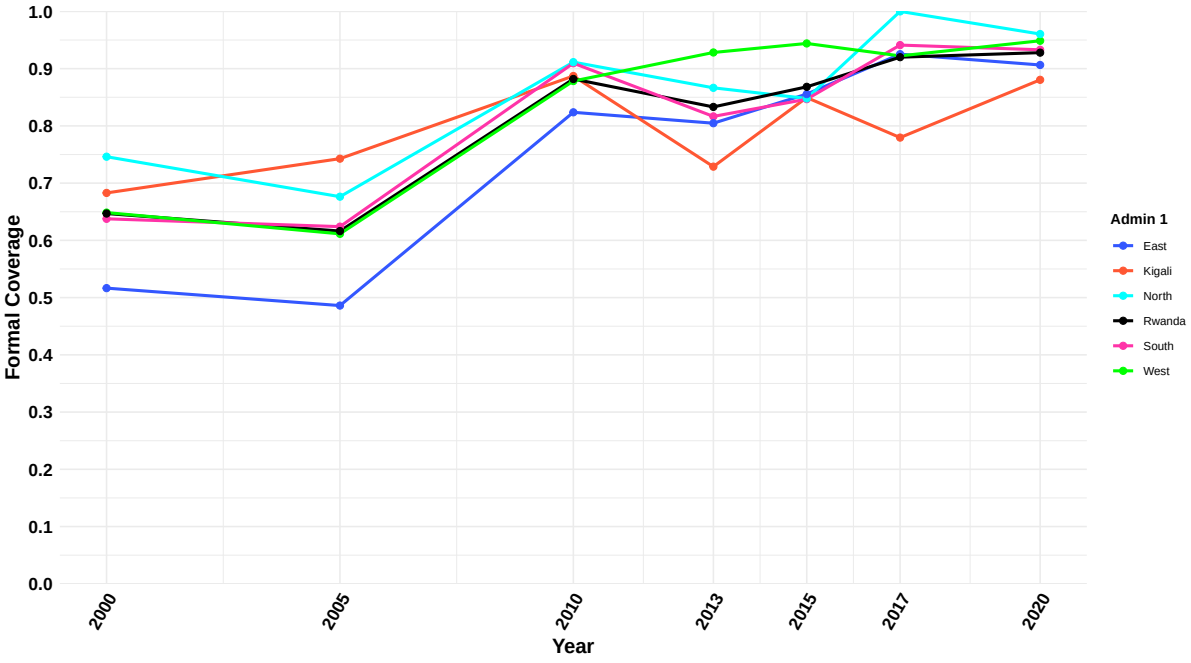

Figure 4.6: Trends in Patients Seeking Treatment from Formal Healthcare Providers by Province

Generally, Kigali City was estimated to have the largest case management indicators compared to other provinces. The Eastern province follows closely, showing remarkable progress, particularly in Compliance and Access. The Northern and Southern provinces demonstrate moderate, steady improvements across all indicators, with Formal measures consistently high. In contrast, the Western province often lags behind, starting from lower baselines in 2000 and showing slower progress, especially in Access and Effective Coverage. Despite these differences, a convergence trend is evident by 2020, particularly in Formal and Compliance indicators.

4.5 Association between the Case Management Indicators and Effective Coverage

Using linear model, we examined the relationship between effective coverage of malaria case management and three predictor variables: access to health care, compliance with first line antimalarial drug , and formal healthcare provider (Figure 4.7).

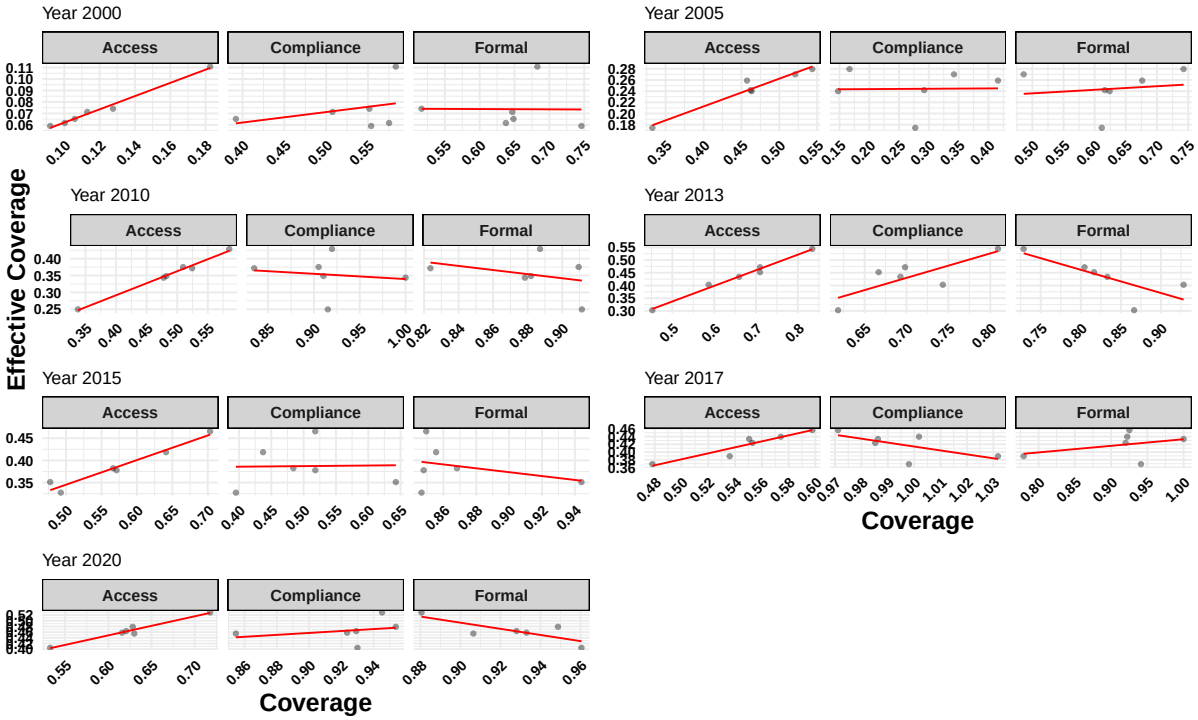

Figure 4.7: Estimated Relationship between the Case Management Indicators and the Level of Effective Coverage (2000-2020)

In 2000, the model shows that access to health care has a significant positive impact on effective coverage, with a coefficient estimate of 0.5859 ($p = 0.00127$). This means that for every 1% increase in access, effective coverage is expected to increase by approximately 58.59%. The formal variable shows marginal significance ($p = 0.0959$), while the compliance variable is not significant. In 2005, access continues to demonstrate a significant positive influence on effective coverage, with a coefficient estimate of 0.4074 ($p = 0.00556$). This indicates that for every 1% increase in access, effective coverage is projected to rise by approximately

40.74%. Neither compliance nor formal care shows significant contributions in this year. In 2010, access remains significant ($p = 0.000214$), with an estimate of 0.6822, meaning a 1% increase in access corresponds to an expected 68.22% increase in effective coverage. Additionally, the formal variable becomes significant ($p = 0.0234$), indicating a positive impact on effective coverage, while compliance does not show significance. In 2013, access continues to be significant ($p = 0.0137$), with a coefficient estimate of 0.4634, implying that a 1% increase in access leads to a 46.34% increase in effective coverage. However, compliance and formal care do not reach significance in this year. In 2015, access remains significant ($p = 0.00208$), with an estimate of 0.3804, indicating a 1% increase in access is associated with a 38.04% increase in effective coverage. The other predictors again do not show significant effects. In 2017, access is highly significant ($p = 0.00025$), with a coefficient estimate of 0.7187, suggesting that a 1% increase in access is expected to increase effective coverage by approximately 71.87%. The formal care variable approaches significance ($p = 0.00393$), indicating a potential positive effect, while compliance is not significant (Table 4.1).

Year	Variable	Estimate	Std Error	P value	Year	Variable	Estimate	Std Error	P value
2000	(Intercept)	-0.0119973	0.0073042	0.2422	2015	(Intercept)	-0.2014995	0.0908217	0.1567
	access	0.585876	0.0208931	0.0013		access	0.620576	0.0283464	0.0021
	compliance	-0.0025654	0.0095574	0.8135		compliance	0.0463163	0.0422578	0.3874
	formal	0.0256348	0.0085673	0.0959		formal	0.239893	0.1109032	0.1630
2005	(Intercept)	-0.0478237	0.0310980	0.2639	2017	(Intercept)	-0.1804213	0.0498951	0.0687
	access	0.508771	0.0380912	0.0056		access	0.766934	0.0121309	0.0003
	compliance	0.0794411	0.0288518	0.1105		compliance	0.0351629	0.0380123	0.4526
	formal	0.0550338	0.0345691	0.2524		formal	0.156979	0.0098725	0.0039
2010	(Intercept)	-0.1650048	0.0275221	0.0267	2020	(Intercept)	-0.3696588	0.0815841	0.0454
	access	0.741758	0.0108513	0.0002		access	0.764118	0.0402531	0.0028
	compliance	-0.0257565	0.0178441	0.2857		compliance	0.1491698	0.0329593	0.0455
	formal	0.205087	0.0319050	0.0234		formal	0.237493	0.0836209	0.1048
2013	(Intercept)	-0.0972572	0.1048413	0.4515					
	access	0.588289	0.0695574	0.0137					
	compliance	0.1344468	0.0913696	0.2790					
	formal	0.0597132	0.1017886	0.6168					

Table 4.1: Linear Model Estimates

In 2020, all three variables achieve significance. Access remains significant ($p = 0.00276$) with a coefficient estimate of 0.5413, meaning that a 1% increase in access leads to a 54.13% increase in effective coverage. Compliance also shows significance ($p = 0.0455$), indicating a positive influence on effective coverage, while formal care is also significant (Table 4.1).

4.5.1 Comparison of Effective Coverage of Malaria Case Management Model Estimates vs. Malaria Atlas Project Data (MAP) .

MAP estimates for effective coverage of malaria case management for Rwanda shows a general upward trend. The coverage starts around 27% in 2000, drops to its lowest point of about 23% in 2003, then steadily increases to a peak of about 38% in 2016-2017, before slightly declining to around 37% by 2021 (Figure 4.8).

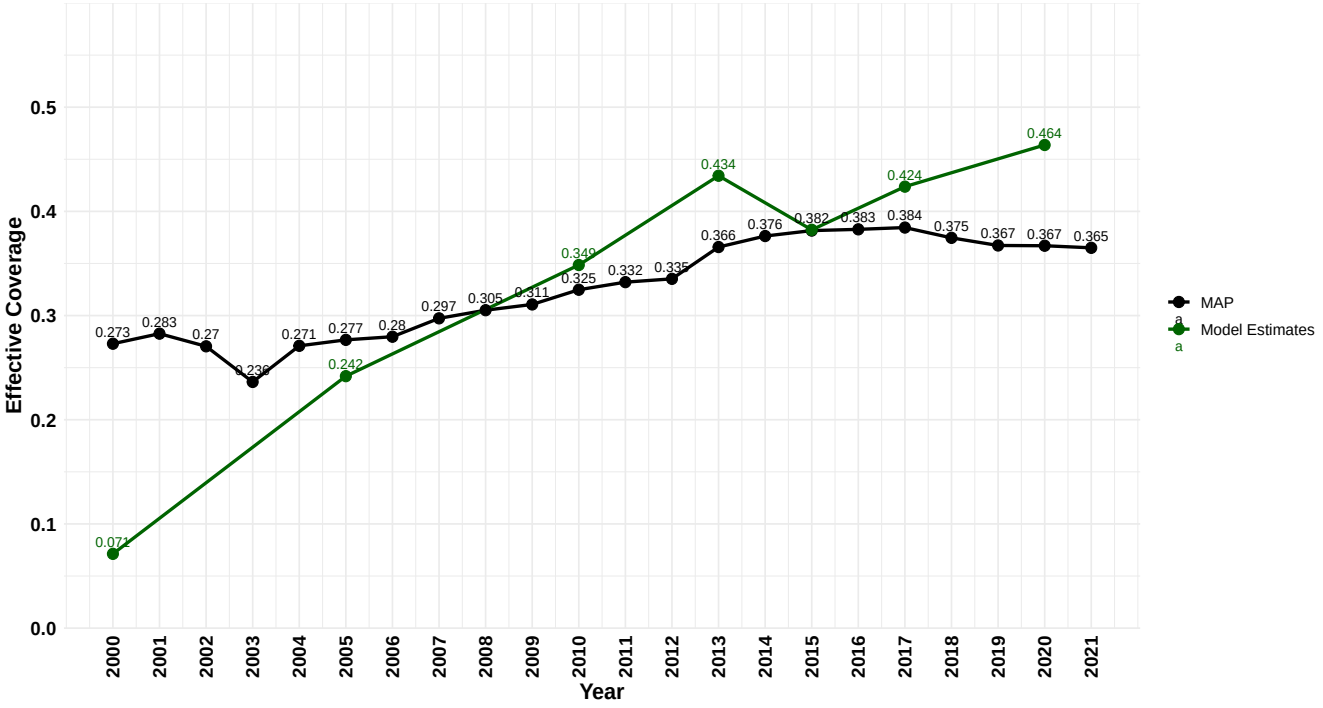

Figure 4.8: Comparison of Effective Coverage of Malaria Case Management over Time

Based on estimations of our model (Figure 4.8) , shows a more increasing trend, and the rate of increase appears to be faster in the earlier years, with some decline between 2013 and 2017. While both data source demonstrate an overall improvement in malaria case management coverage over time, there are significant differences in the values and the pattern of change.

4.5.2 Comparison of effective coverage model estimates vs. malaria atlas project data at provincial Level.

There's a general upward trend in effective coverage for all provinces over the 21-year period for both model estimates and MAP. Our model estimates show that Kigali has a steeper increase and higher overall effective coverage compared to MAP data.Initially, from 2000 to 2004, MAP data indicated consistent treatment rates of approximately 30-35%. The model began at a lower level but rapidly aligned with the MAP data. By the final period, from 2017 to 2021, the model exhibited higher treatment rates of 50-55%, compared to the MAP data's rates of 40-45% with the gap widening significantly after 2010. The East province indicates closer alignment between MAP data and model estimates, though estimates tend to be slightly higher, particularly in later years (Figure 4.9).

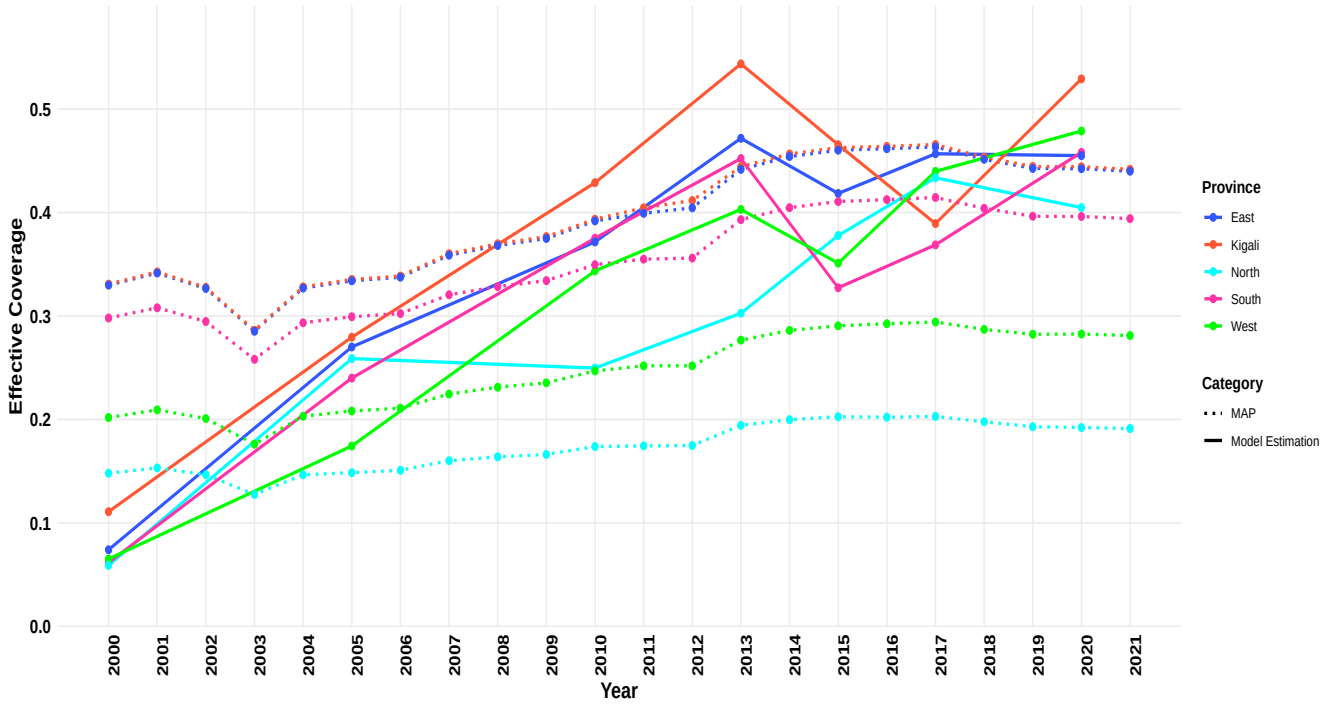

Figure 4.9: Comparison of Effective Coverage of Malaria Case Management at Provincial Level

The Northern Province displays a variance, with model estimates consistently and substantially higher than MAP data throughout the entire period. Early MAP data showed low, steady rates (15-20%). The model started very low but grew quickly. In recent years, the model shows much higher effective coverage rates (40-45%) than MAP data (about 20%). The South province shows relatively good agreement between MAP and model data, with some divergence in the middle years but convergence towards the end. The West province exhibits a pattern similar to Kigali, where model estimates increase more rapidly and reach higher levels than MAP data, especially after 2010. MAP data started steady at about 20%. The model began very low but grew fast, passing MAP data by 2004. In recent years, the model shows higher rates (45-50%) than MAP data (around 28%), but both show improvement (Figure 4.9).

Generally, model estimates tend to show more dramatic increases while MAP data presents a smoother, more gradual upward trend across all provinces.

Practical Work within the Rwanda Biomedical Centre

During my internship at the Rwanda Biomedical Center (RBC), I was actively involved in several key activities that greatly enhanced my understanding of malaria case management and intervention strategies. One of the primary activities was participating in the presentations of six MaMod students' projects to the National Malaria Control Program (NMCP) leaders. This session provided valuable feedback on improving our projects, particularly concerning data availability and the potential benefits of our work for the malaria program. The division

manager's inputs were instrumental in refining our approaches and ensuring that our projects aligned with the NMCP's objectives.

Another significant aspect of my internship was attending a workshop organized by RBC in Musanze District, focused on developing and validating the annual malaria report. The workshop, which lasted a week and involved nearly all NMCP staff, provided an immersive experience in data management. I worked closely with field experts on tasks such as data cleaning, creating visualizations, checking report grammar, and developing content. This hands-on involvement allowed me to gain a deeper understanding of how data is utilized in malaria case management, vector control, and prevention interventions.

Additionally, I participated in an investigation into the increase of malaria cases in Gisagara District. This investigation involved several critical activities, including recounting malaria indicators from hospital and community health records, assessing environmental factors and local health facility capacities, and conducting geospatial mapping of malaria hotspots. The process also included community engagement and geographical data analysis. My role in data visualization and case counting, coupled with compiling findings into a comprehensive report with recommendations, provided valuable insights into the factors influencing malaria case increases and the effectiveness of current interventions.

Lastly, I took part in an entomology field visit, which was focused on vector control projects. This visit offered practical experience in vector management strategies and field operations, further enhancing my knowledge and skills in malaria vector control.

4.6 Discussion

The significant rise in malaria case management in Rwanda, growing from 7% in 2000 to 46% in 2020, shows a major public health success over the last two decades. This advancement shows that by 2020 nearly half of malaria cases in Rwanda received effective treatment, compared to just a small fraction 7% in two decades ago. At the start of the millennium, Rwanda's malaria burden was extremely high, with limited access to effective treatment. Malaria accounted for more than 50% of outpatient visits and was a leading cause of mortality. The low effective coverage rate of 7% in 2000 reflects the limited access to appropriate diagnostic and treatment tools. Effective malaria treatment relies on the successful completion of every stage in the service delivery process. If any stage is missed or fails, the infection may be inadequately treated or left untreated, making it essential for all steps to be effective in achieving effective coverage of malaria case managements. Therefore, maintaining high standards throughout the entire process is crucial for achieving satisfactory levels of effective coverage. Our findings indicate that improvements are needed at each stage.

The Rwandan government implemented artemisinin-based combination therapy (ACT) at the community level in 2006, followed by the introduction of RDTs in 2009, marked a significant milestone in Rwanda's malaria control efforts. These interventions resulted in an increase in easy access to the healthcare providers and treatment which enhanced an increase in effective treatment coverage, from 7% to 46% by 2020, demonstrating their critical role in reducing malaria morbidity and mortality. CHWs played a critical role in this success, as their training in administering RDTs and ACTs which expanded access to prompt and accurate diagnosis and treatment, particularly in rural areas. By 2013, effective coverage reached its highest point

of 44%, showing the contribution of Rwanda's community health worker network, strong political will, and partnerships with global health organizations. However, a slight decline in coverage to 38% in 2015 may point to challenges such as stock-outs of diagnostic tools or antimalarial drug, delays in training new health workers, delay in interventions such as IRS, ITN distribution, or logistical issues. Rises in coverage in last two decade is result from improved healthcare infrastructure, such as the construction of new health centers in underserved place in Rwanda, the implementation of mobile clinics to reach remote populations, malaria home based management. Increased access to antimalarial drugs, perhaps through better supply chain management or partnerships with international pharmaceutical and Rwanda Medical Supply (RMS), likely played a role in the steady climb to 43% by 2013. Public awareness campaigns, such as radio broadcasts about recognizing malaria symptoms and the importance of prompt treatment, may have encouraged more people to seek care, further improving coverage.

Declines in effective coverage could meet from various challenges. The decrease to 38% in 2015 could have been due to Malaria drug stock-out, financial pressures or wrong allocation of resources to healthcare institutions and CHWs. Drug resistance is another potential factor; if parasites develop resistance to first-line treatments, it temporarily reduce effective management until new drugs are established.Environmental factors also played a role—unusually heavy rainy seasons led to a growth in the mosquito population. For example, in Shyembe village, a place in Gisagara District surrounded by bushes, a river, and mineral extraction sites, there has been a high burden of malaria cases. Additionally, malaria is perceived as less of a threat due to initial gains, it resulted in reduced efforts in intervention deployment to fight against malaria.

However, it's important to note that while the improvement is substantial, more than half of malaria cases still do not receive effective management. This indicates there's still considerable room for further progress in Rwanda's malaria control efforts.

All provinces experience a significant jump in effective coverage between 2010 and 2013, suggesting a possible nationwide intervention or policy change that positively impacted malaria case management. Kigali was estimated to have the high effective coverage compared to other region, likely due to its status as the capital and primary urban center, its superior healthcare infrastructure, proximity to resources, and higher socioeconomic status, which allow for better access to diagnostic tools and treatments. In contrast, rural regions like the North and West province face challenges such as fewer healthcare facilities, logistical delays, lower socioeconomic status, and cultural barriers, which limit timely access to malaria treatment and slow progress in improving coverage. The rise in access, compliance and formal care seeking between 2015 and 2017 have been due to an expansion of the community health worker program and improved distribution of rapid diagnostic tests (RDTs) and artemisinin-based combination therapies (ACTs) and Sensitization.

The analysis of linear model across the surveys years shown that access to healthcare is the most correlated factor driving effective coverage of malaria case management. In each year examined, access demonstrates a significant positive relationship with effective coverage, with the size of this effect varying slightly but remaining strong overall. The impact of formal care appears to increase over time, particularly in 2010 and 2017, when it approaches or achieves significance, suggesting that as healthcare systems formalize, they begin to contribute more substantially to coverage. Even compliance was not significant in earlier years, its contribution in 2020 suggests that changes in behavior, policy, or healthcare infrastructure may have

enhanced the role of compliance in improving healthcare outcomes during that period 2015-2020 (Table 4.1). It is more important to focus on improving access to healthcare services as a central strategy for increasing effective coverage of malaria case management. While formal healthcare systems are becoming more significant, the lack of a consistent relationship between compliance and coverage suggests that further efforts may be needed to improve patient adherence to treatment protocols, particularly as formal systems expand.

Both data source Malaria Atlas project and DHS/MIS demonstrate an overall improvement in malaria case management effective coverage over time, there are significant differences in the values and the pattern of change (Figure 4.8). These differences could be attributed to variations in methodologies, data sources, and existing estimates, such as cure rates, substandard antimalarial drug rates, and other parameters used in each approach. The Atlas MAP data incorporate a broader range of factors and use more conservative estimates, while the estimation data from These differences could be attributed to variations in methodologies, data sources, and existing estimates, such as cure rates, substandard antimalarial drug rates, and other parameters used in each approach. The Atlas MAP data incorporate a broader range of factors and use more conservative estimates, while the estimation data from DHS and MIS datasets focus on specific and targeted indicators. It's important to note that while both datasets show progress, they also highlight the ongoing need for improved malaria case management. Even at their highest points, neither graph shows coverage reaching 50%, indicating that there is still significant room for improvement in ensuring effective treatment reaches all those affected by malaria.

The model assumes that if a child under five does not access any healthcare provider, the effective coverage is zero, which oversimplify real world scenarios. It also assumes that formal providers are government recognized, while informal providers are illegal, possibly missing the nuances of healthcare in rural areas. Additionally, the data used focus solely on children under five, covering the period between 2000 and 2020, which limits its generalizability to adults or more recent trends. To improve the model, future work include DHS 2023 data and adult populations. These extensions would provide a more accurate and comprehensive understanding of malaria case management in Rwanda.

In conclusion, Rwanda has made an effort in managing malaria cases over the last 20 years represents a significant public health achievement, with effective treatment coverage expanding considerably. Key interventions, such as the introduction of artemisinin-based combination therapies (ACTs), rapid diagnostic tests (RDTs), and the crucial role of community health workers, have greatly improved access to care, particularly in rural areas. However, challenges like drug stock-outs, logistical issues, and environmental factors have led to variations in coverage, revealing areas that still need improvement. While both the Malaria Atlas Project (MAP) and DHS/MIS data show consistent advancements, they also emphasize that a significant portion of malaria cases remains untreated or inadequately managed. This highlights the need for continued efforts to address these gaps, ensuring more equitable access to effective malaria treatment across all regions of Rwanda.

5. Conclusion

Malaria persist as a pressing health issue in Rwanda, where it affects countless lives and strains the healthcare system. The study modeled the effective coverage of malaria case management in Rwanda using a decision tree framework that considered health-seeking behavior, provider compliance, patient adherence, and drug quality, with data from the Demographic and Health Surveys (DHS) and Malaria Indicator Surveys (MIS) between 2000 and 2020. The model revealed that Rwanda has achieved progress in malaria case management over the past two decades, with effective coverage increasing from 7% in 2000 to nearly 46% by 2020. However, challenges persist, as more than half of malaria cases still lack effective management, highlighting the need for sustained efforts. Regional disparities are evident, with Kigali consistently leading in effective coverage due to its superior healthcare infrastructure and socioeconomic status, while rural provinces like the North and West encounter obstacles that hinder the progress. Despite these advancements, the ongoing focus on enhancing access, compliance, and overall effective coverage remains critical to further reducing the malaria burden in Rwanda. Additionally, both the Malaria Atlas Project (MAP) and DHS/MIS data underscore that while substantial improvements have been made, many malaria cases remain untreated or inadequately managed, with coverage still below 50%. This reveals the need for continued efforts to enhance equitable access to effective malaria treatment across all regions in Rwanda, particularly through addressing stock-out issues, improving healthcare infrastructure, and focusing on treatment adherence. The study is limited to only children under five data, which might impact the overall effective coverage estimates of malaria case managements in Rwanda. We would highly recommend , enhancing patient education to improve treatment adherence, Strengthening diagnostic capabilities to ensure accurate treatment, Implementing robust systems for monitoring drug resistance, Improving supply chain management to maintain drug quality, and Providing continuous training for healthcare workers especially CHWs on evolving malaria treatment protocols.

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